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THE REQUIREMENTS FOR A FAMILY OF AERONAUTICAL CHARTS

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Prepared for

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THE REQUIREMENTS FOR
A FAMILY OF AERONAUTICAL CHARTS

Dunlap and Associates, Inc.
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SUMMARY

Problem

The purpose of this investigation was to develop the requirements for a "family" of aeronautical charts to meet the over-all needs of Naval air navigation in an efficient manner. The problem is one of determining the different functional types of charts and the general design features of each, taking the pertinent factors of Naval flight and air navigation into consideration.

Procedure

The requirements for the family of charts were derived from an examination of existing charts, an identification of flight factors which relate to chart design, and the analysis of pertinent operational data on Naval air squadrons and missions.

Discussion

On a logical basis the framework for the total family of charts was schematized, and the operational data were analyzed to indicate specific requirements for member charts. Some portions of the family of charts received only preliminary treatment since the amount of experimental data pertaining to aeronautical charts is limited. Further research, utilizing job analysis and testing techniques, is necessary in order to yield a more complete picture and to determine detailed chart specifications.

Recommendations

The variety of aeronautical charts required to fulfill the needs of Naval air navigation may be categorized according to three phases of flight (planning, en route, and destination) and, basically, may be one of three functional types (pilotage, plotting, or electronic). Within this schema a specific variety of charts is necessary to insure proper coverage of Naval air navigation.

The number and type of charts which are recommended to cover the needs of Naval airmen cannot be easily summarized. These recommendations, together with recommendations pertaining to future studies, are presented in full in Chapter V of this report.

I. INTRODUCTION

A. Background of the Problem

An investigation into the historical development of aeronautical charts reveals a trend away from the production of "all-purpose" charts toward the production of "limited-purpose" charts.[1] The design of the former was curtailed when it became evident that a satisfactory combination of features and information could not be presented on a single type of chart. Limited purpose charts, on the other hand, developed in answer to technological advances in aircraft and navigation instruments. The rapid expansion of air navigation during World War II incited numerous revisions and new charts. However, no consistent theory or general plan seemed to control the variations which occurred.

A copy of each basic chart currently available to Navy airmen was requested and received from the Hydrographic Office. These charts are listed in Table I in three groups, representing the three Government agencies responsible for their development.

The charts listed in Table I were examined in order to obtain a picture of similarities and differences among them. Supplementary information was gathered by referring to manuals issued by Government agencies. The main intention was to see if the years of individual chart design and periodic revisions had led to a group of charts which satisfied all of the needs of the airmen without unnecessary duplication. As might be expected, since separate agencies and many men were involved in their development, current charts proved to be characterized by a variety of titles and many designated purposes which did not fit easily into a well-defined functional grouping.

Table II summarizes the essential features--the designated purpose, type of projection, information presented, size, scale and total area covered--of the charts produced by the three agencies. A slight trend may be noted: HO produces charts for over-water navigation, ACIS is concerned with charts for traversing land-mass areas,

[1] KISHLER, J. P., WATERS, R. H. & ORLANSKY, J. The development of graphic aids to air navigation. Office of Naval Research, Contract N8onr-641-05, ONR Report No. 641-05-1, 29 May 1951.

Table I.

Types of aeronautical charts currently issued to Naval Air Activities

Code number	Name
Hydrographic Office (HO)	
V-30-28	Air Navigation Chart
VS-10	Air Traffic Control Charts
VR-212	Pacific Airways Plotting Chart
L14-227	Loran Chart
VL-70-10	Loran Air Navigation Chart
VL30-28	Loran Air Navigation Chart
VRL 210	Loran Pacific Airways Plotting Chart
Aeronautical Chart and Information Service (ACIS)	
500-B1(G)	(AAF) Aeronautical Approach Chart (AC)
AP-14	(USAF) Aeronautical Planning Chart
AN-136	(USAF) Air Navigation Chart
ZD-11A	Azimuth Equidistant Chart
FC-277	(USAF) Flight Chart
LR-27	(USAF) Long Range Navigation Chart
NF-11	(USAF) Navigational Flight Chart
500A	(USAF) Pilotage Chart (PC)
NS-117	Special Air Navigation Chart
PS-503	(USAF) Special Plotting Chart
XJN	Experimental Jet Navigation Chart
500G	World Aeronautical Chart
US Coast and Geodetic Survey (USCGS)	
AL-804-ADF	Approach and Landing
AL-804-VOR	Approach and Landing
AL-580	Approach and Landing
AL-443-ILS	Approach and Landing
T-9	Sectional Aeronautical Chart
	Washington Local Aeronautical Chart

TABLE II

ESSENTIAL FEATURES OF AERONAUTICAL CHARTS CURRENTLY IN USE

	H.O.							A.C.I.S.											
	Air Navigation Chart	Air Traffic Control Chart	Airways Plotting Chart	Loran Chart	Loran Air Nav. Chart	Loran Air Nav. Chart	Loran Pacific Plotting Airways	Aeronautical Approach Chart	Aeronautical Plan Chart	Air Navigation Chart	Azimuth Equi. Chart	Flight Chart	Long Range Navigation Chart	Navigation Flight Chart	Pilotage Chart	Spl. Air Navigation Chart	Spl. Plotting Chart	XJN	WAC
CODE NUMBER	V30-28	VS-10	VR-212	L14-227	VL 70-10	VL30-28	VRL-210	500-BI(G)	AP-14	AN-136	ZD-11A	FC-277	LR-27	NF-11	500A	NS-117	PS-503	XJN	500-G
DESIGNATED PURPOSE[1]																			
Plng. & Trng.		X							X	y	X								
Apch. & Ldg.																			
Celestial Nav.	X		X				X					y	X	X		X	X		y
Dead Reckoning	X		X				X			X		y		X	X	X	X		y
Loran Navigation				X	X	X	X												
Pilotage (C)	X							X		X		X	y		X	X		X	X
Radio Navigation	X		X				X	y				X	y		y	y	y	X	X
PROJECTION[2]											X[10]								
Mercator	X	X	X	X	X	X	X			X		X	X	X		X	X		
Lambert								X	X			X	X		X			X	X
Stereographic								X	X				X		X				X
INFORMATION																			
Hydrographic	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Terrain	X		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Cultural	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Radio	X	X	X			X	X		X	X		X	X	X	X	X	X	X	X
Loran				X	X	X	X												
Legal & Security[3]		X						X	X	X		X	X	X	X	X		X	X
UTM grid								X											
Georef grid															X				X
Minimum[4]						X	X										X		
SCALE (Approx.)[5]																			
1: 250,000								X											
1: 500,000									X						X				
1:1,000,000				X						X		X		X					X
1:2,000,000	X					X								X					
1:3,000,000			X				X						X	X			X		
1:4,000,000			X				X												
1:4,377,740			X				X											X	
1:5,000,000			X		X		X									X			
Various											X								
SIZE (Approx.)																			
54 x 35 inches	X[6]					X													
52 x 40 inches													X[7]						
52 x 33 inches					X														
51 x 35 inches										X									
47 x 32 inches									X[7]										
42 x 24 inches																			
40 x 30 inches			X				X												
29 x 22 inches								X							X				X
27 x 53 inches											X[7]								
19 x 17 inches																		X	
8 x 10 1/2 inches																			
Various		X		X								X[9]		X		X	X		
TOTAL AREA COVERED[8]																			
Small ((0- 500)								99 x 75				X			199 x 151				397 x 302
Middle (500-1000)				X						699 x 480		X							
Large (Over 1000)	1480 x 959	X	1645 x 1234		3563 x 2261	1480 x 959	1645 x 1234		3221 x 2193		X		2138 x 1645	X		X	X	1125 x 960	

[1] X denotes primary purpose; y is secondary.

[2] Where more than one type is checked, Mercator is used in Equatorial regions; Lambert in middle latitudes; Stereographic in polar regions.

[3] Refers to boundaries and security areas.

[4] Minimum refers to limited information.

[5] More than one check indicates range of values.

[6] Approximate value.

[7] Average value.

[8] Mileage along one edge.

[9] Charts are 14 x 30 1/2, 45 or 59 1/2.

[10] Azimuthal Equidistante projection centered on chart name.

2

TABLE II
ESSENTIAL FEATURES OF AERONAUTICAL CHARTS CURRENTLY IN USE

H.O.					A.C.I.S.												U.S.C.G.S.					
ys ing t	Loran Chart	Loran Air Nav. Chart	Loran Air Nav. Chart	Loran Pacific Plotting Airways	Aeronautical Approach Chart	Aeronautical Plan Chart	Air Navigation Chart	Azimuth Equi. Chart	Flight Chart	Long Range Navigation Chart	Navigation Flight Chart	Pilotage Chart	Spl. Air Navigation Chart	Spl. Plotting Chart	XJN	WAC	Approach and Landing	Approach and Landing	Approach and Landing	Approach and Landing	Local Aero. Chart	Sectional Aero. Chart
12	L14-227	VL 70-10	VL30-28	VRL-210	500-BI(G)	AP-14	AN-136	ZD-11A	FC-277	LR-27	NF-11	500A	NS-117	PS-503	XJN	500-G	AL-804-ADF	AL-804-VOR	AL-580	AL-443-ILS	Wash.	T-9
						x	y	x														
																	x	x	x	x		
				x					y	x	x		x	x		y						
				x			x		y		x	x	x	x		y						
	x	x	x	x																		
					x		x		x	y		x	x		x	x					x	x
				x	y				x	y		y	y	y	x	x					x	y
								x[10]														
	x	x	x	x			x		x	x	x		x	x								
					x	x			x	x		x			x	x					x	x
					x	x				x		x				x						
	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
			x	x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
	x	x	x	x																		
					x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x
					x																	
												x				x						x
			x	x										x								
					x																x	
						x						x										x
	x						x		x		x					x						
			x								x											
				x						x	x			x								
				x																		
				x											x							
		x		x									x									
								x														
			x																			
										x[7]												
		x																				
							x															
						x[7]																
																						x
				x																		
					x							x				x					x	
								x[7]														
															x							
																	x	x	x	x		
	x								x[9]		x		x	x								
					99 x 75				x			199 x 151				397 x 302	27 x 36	27 x 36	27 x 36	27 x 36	99 x 75	288 x 164
	x						699 x 480		x													
1234		3563 x 2261	1480 x 959	1645 x 1234		3221 x 2193		x		2138 x 1645	x		x	x	1125 x 960							

r is used in Equatorial
phic in polar regions.

[4] Minimum refers to limited information.

[5] More than one check indicates range of values.

[6] Approximate value.

[7] Average value.

[8] Mileage along one edge.

[9] Charts are 14 x 30 1/2, 45 or 59 1/2.

[10] Azimuthal Equidistante projection centered on chart name.

and the USCGS provides charts for more precise navigation. However, this trend is far from consistent, and the main impression created by Table II is the lack of any obvious systematic basis for chart construction. There may be a reason for the use of a specific size or scale and its relation to, say, the information presented or the designated purpose; but this reason is not apparent upon first examination.

A similar impression is created by current chart specifications and catalogues. The International Civil Aviation Organization publishes the "Current Standards and Recommended Practices."[1] They outline how to construct a number of widely recognized types of aeronautical charts, but the rational basis for the specifications is not provided. Government cartographic agencies[2, 3] simply catalogue series of aeronautical charts published and state briefly the purpose for which the charts are designed; titles and designated purposes are not fitted into any systematic plan.

Finally, Deetz[4], in his book on cartography, devotes only one page to considerations peculiar to aeronautical chart construction. Thus, the available evidence suggests that the variety of aeronautical charts which exist today are simply not accompanied by printed rationale which will account for their differences.

B. Purpose of the Report

Aeronautical charts are a means of showing spatial relationships and conveying information which will allow and assist the navigational tasks of airmen. By their design, charts should provide required information in a form appropriate to the conditions under which they will be used.

---

[1] Aeronautical charts: standards and recommended practices. International Civil Aviation Organization, Montreal, Canada, December 1950.

[2] USAF catalog of aeronautical charts. Ninth edition. Aeronautical Chart and Information Service, December 1951.

[3] Aeronautical chart catalog. U.S. Coast and Geodetic Survey, September 1950.

[4] DEETZ, C. H. Cartography. A review and guide. Washington, D.C.: U.S. Government Printing Office, 1943.

The aim of the present investigation was to develop the requirements for a "family" of aeronautical charts. A "family" is defined as a group of functionally-related charts, organized to meet the overall needs of Naval air navigation in an efficient manner. Each chart in the family should have a reason for its distinct existence. The variations which occur in the family should be those which are necessary to fulfill different aspects of air navigation. Overlap of information and design features should be such that the general utility of individual charts is increased without disturbing their primary function.

In order to determine the general requirements for aeronautical charts, the present investigators analyzed flight factors and conditions demanding certain chart characteristics. Then, in deriving the requirements for a family of charts, they made use of information obtained from an examination of present charts, a study of methods of air navigation, and an analysis of operational data on Naval air squadrons and missions. The operational data were used primarily to determine the specific characteristics of charts included as members of the basic family.

Although the study does not provide <u>final</u> specifications for a family of charts, it should be recognized as an important first step toward solving a large and complex problem. The next steps should be 1) verification of the findings by a thorough analysis of the navigator's job and 2) experimental testing of the recommendations.

The report is organized as follows:

I. Introduction
II. General Requirements for Aeronautical Charts
III. Outline for a Family of Charts
IV. Specific Requirements for Member Charts
V. Recommendations

II. GENERAL REQUIREMENTS FOR AERONAUTICAL CHARTS

When a chart is being developed, decisions must be made with regard to the features it contains. The possible number of such features is immense. For purposes of analysis, however, they can be treated in terms of the following six general chart characteristics:

1. Type of projection
2. Amount and type of information
3. Size of chart
4. Scale of chart
5. Total area coverage
6. Cartographic detail

In order to insure that the charts are functional, it is necessary to consider the factors of flight which may influence chart requirements. These factors are listed below:

1. Navigational procedures
2. Region flown over
3. Accuracy required
4. Flight speed
5. Navigational facilities (space, lighting, etc.)
6. Flight altitude
7. Combat radius
8. Electronic gear

The first three factors are the chief determiners of the general nature and appearance of the major aeronautical charts. The last five factors may be more precisely identified as conditions of flight, variations in which may make it desirable (from the point of view of the airmen) to alter the combination of chart characteristics and construct sub-varieties of charts. Each of the general chart characteristics, and the variations demanded by particular flight factors, are discussed in the remainder of this section.

A. Type of Projection

Charts may differ markedly in the manner in which the spherical surface of the earth is represented on a flat piece of paper. Some distortion is inherent in the process of depicting a globe in two dimensions and thus one can only approximate the qualities of the ideal aeronautical chart which would convey true directions and distances between all points. The nature and capabilities of the various projections may be inspected in the references cited.[1,2] The flight factors which relate to or influence the type of projection utilized on aeronautical charts are as follows:

1. Navigational Procedures

Air navigation procedures require that a chart have a coordinate system which allows convenient and accurate measures for plotting of courses, distances and lines of position. The extended view which flight provides also suggests the need for conformality or the depicting of true shapes. In general, the decision to use one projection rather than another depends on the particular plotting and measuring requirements and their relation to the distortions peculiar to a given projection. Current practice appears to favor the Lambert Conformal for air navigation in general as well as for those charts of land-mass areas where pilotage procedures will be used. The Mercator is sometimes preferred for the accurate dead-reckoning necessary in traversing extended water areas.

2. Region Flown Over

The inherent accuracy of the different projections changes for different regions of the globe. Some projections are good for middle latitudes and others are suitable for polar areas. The Sterographic projection is commonly substituted for the Lambert Conformal or Mercator for navigation above 80° latitude.

3. Accuracy Required

The accuracy required to fulfill certain missions may influence the selection of a projection, since different projections yield different kinds and degrees of accuracy.

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[1] DEETZ, C. H. & ADAMS, O. S. Elements of map projection with applications to map and chart construction. Washington, D.C.: U.S. Government Printing Office, 1945.

[2] Map projections and coordinate systems. Photographic Interpretation Handbook Supplement No. 19, Photographic Intelligence Center, Division of Naval Intelligence, Navy Department, 1 February 1946. (RESTRICTED)

B. Amount and Type of Information

A chart is primarily a means of imparting information. What exists in the area portrayed sets the upper limit on what information might be depicted. However, the information actually included is the result of a selective process and decisions have to be made as to "what kind" and "how much." In general, displayed features should be visible, discriminable, recognizable and useful to the navigator. The nature of what is depicted, however, may vary markedly. Rivers, roads, race tracks, air routes, radio stations, etc., may or may not be included. Decisions must be reached as to the number of different types of information presented and the number of items within each type. Flight factors which relate to the type and amount of information appearing on an aeronautical chart are as follows:

1. Navigational Procedures

Any information which appears on a chart should ultimately be related to the procedures of navigation. The major functional types of charts which will be outlined later are grouped on the basis of the navigational procedures which they seek to satisfy and are distinguished by the general nature of the information they impart. Pilotage calls for depicting recognizable landmarks. Celestial and dead-reckoning emphasizes features for plotting and measuring convenience. Electronic navigation calls for the conveying of the location of radio stations, beacons, frequencies, call letters, etc.

2. Region Flown Over

The region being navigated or for which the chart is constructed may grossly alter the information depicted. The gross contrast of land versus water areas, highly-settled regions versus wasteland, etc., may be noted. This factor should also be considered in selecting specific landmarks. A British airman has put it this way: "One feels that a standard presentation for all parts of the world is also wrong. A rabbit fence on a map of Pennsylvania would be ludicrous--a rabbit fence on a map of Australia is essential, for it is an excellent landmark at very high altitudes."[1]

[1] LANGSTON, J. Practical aspects of high speed navigation. ATC Informational Bulletin, Fall 1951.

3. Electronic Gear

The popularity of various electronic devices relates to the nature and amount of electronic information included on any aeronautical chart. It may be reasonable to include radar beacons and radio compass facilities on a pilotage chart when these devices are commonly used in conjunction with visual fixing of position. Further, specific charts may be required in order to facilitate navigation solely by means of radar, loran, or radio compass.

4. Flight Altitude

The altitude at which a flight is being conducted relates to the size and possible number of ground referents which might be depicted on a chart per unit area. At higher altitudes only the larger and more distinct referents can be recognized. (Flight altitude would appear to be of no consequence for plotting charts of ocean areas or for charts for IFR flight unless, of course, certain electronic facilities do not function well at certain altitudes.)

5. Flight Speed

The speed at which the countryside is being traversed relates to the amount of information included on a chart. At higher speeds a fewer number of visual fixes are possible per unit area of land traversed. Again, at higher speeds a fewer number of fixes per land area traversed seem necessary, since wind errors decrease as speed increases. The same arguments apply to flight under IFR conditions except, of course, that position is determined by dead-reckoning or electronic means. Higher speeds tend to emphasize the importance of including distinct referents which can be quickly recognized or identified.

6. Accuracy Required

An increase in the accuracy required will generally mean an increase in the amount of information or detail which a chart conveys since this may be necessary to determine position more precisely.

C. Chart Scale

The ratio in linear units of the distance between two points on a chart and the corresponding distance on the earth's surface is known as the scale. Making the scale of a chart larger is equivalent to showing less area of the earth per square inch. It allows a more detailed "photo" of the earth. A small scale has the opposite effect. Scales employed on "universal" series at the present time range from the 1: 250,000 of the Local Aeronautical Chart to the 1: 5,000,000 of the Loran and Plotting Charts produced by the Hydrographic Office. Conditions of flight which are directly related to the scale selected for a chart are:

1. Flight Speed

Flight speed relates to the scale of a chart in that keeping track of position on a chart becomes more difficult when the movement across the chart is increased. After 15 minutes a plane traveling at 400 knots will fly 14.6 inches on a 1: 500,000 scale. This yields a large and detailed area on the chart for a pilot to be concerned with. A smaller scale will reduce the area and detail, allowing him to keep track of his position more conveniently.

2. Accuracy Required

Where great accuracy is required, such as in aerial minelaying, a very large scale is needed to minimize plotting errors. The location of precise points, airports, targets, etc., normally requires an increase in scale.

D. Chart Size

The physical dimensions of the chart may be varied. Thus charts have been cut in small sizes equivalent to a book page or in very large cumbersome sheets of 40 x 50 inches. Aeronautical charts must be handled and used in circumstances which are far from ideal; these circumstances, and the chart sizes selected, relate primarily to navigational facilities. The facilities available for using a chart vary from plane to plane and are often related to responsibility and the time available for the job of navigation with a chart. Obviously, larger more convenient spaces allow for the handling of larger charts. Large planes which provide a special table and station for navigation usually carry a special man who can devote greater attention to handling a chart, while the pilot who must navigate in the cockpit has varied responsibilities coincident with his cramped quarters.

Past decisions to use large charts with numerous folds have been due to the desire to have great area coverage without reducing the chart's scale. Area coverage and scale considerations were primary, convenience of handling or regard for the restrictions of plane space were sacrificed. However, in most cases, large charts with numerous folds are not desirable since they are often a source of irritation and greatly inhibit access to legend data.

E. Area Coverage

The total area of the earth which a chart covers may vary. The value for a particular chart will depend directly on its scale and sheet size since these variables are intimately related. However, the area coverage value receives independent concern primarily because of combat radius and flight speed.

1. Combat Radius

The distances which different planes can fly will vary. In order to minimize the chances of "flying off a chart" and requiring a change in charts en route, planes which can fly longer distances may well utilize charts which provide greater total area coverage. Since, however, there is a limit to the size of a chart which can be manipulated readily in an airplane, extreme ranges would appear to favor smaller scales and/or more charts.

2. Flight Speed

High-speed planes naturally tend to traverse the area of a chart more rapidly. Increasing the total area coverage for the faster planes (using a smaller scale, if possible, to keep the sheet size down) will tend to minimize the number of chart changes necessary en route per unit of time.

F. Cartographic Detail

This final chart characteristic refers to the variation which may occur in a series of specific aspects of chart construction. The combination of paper, ink, printing, colors, symbols, format, etc., which make up a chart have to be decided upon. The considerations which indicate their nature are not all essentially peculiar to air navigation or directly related to conditions of flight. The "readability" of a chart is of major concern. Clutter may be greatly alleviated by better cartographic techniques. As the scale of a chart decreases and the information required increases the problem of cartographic representation becomes one of reconciling conflicting requirements in favor of the users' paramount needs. A body of knowledge has accumulated in cartographic agencies and some principles of cartographic representation have been supported by research studies concerned with chart evaluation.[1,2,3]

Table III summarizes the foregoing analysis. This table may be used conveniently to remind one of the flight factors which need consideration as decisions are made concerning the general features of a chart.

Secondary effects increase the complexity of the problem and merit some attention. Chart variables are so interdependent that a change in one results in changes in one or more of the others. The manner in which such changes affect other variables is presented in the following listing:

1. Type of Projection

   Increases in area coverage may decrease the accuracy and suitability of the various projections. For example, the generally acceptable Lambert Conformal projection introduces troublesome distortions if used over wide areas of latitude.

2. Information

   Smaller scales may force the elimination of some types of information in crowded areas.

3. Scale

   An increase in information may dictate that the scale be increased to show the necessary amount of information if the cartographic details cannot be reasonably decreased in size.

---

[1] MURRAY, J.E., WATERS, R.H. & ORLANSKY, J. An evaluation of two experimental charts designed for navigation in high-speed, high-altitude aircraft. Office of Naval Research, Contract N8onr-641, T.O. 5, ONR Report No. 641-05-6, 15 May 1952.

[2] KOPONEN, A., WATERS, R.H. & ORLANSKY, J The associational value of aeronautical chart symbols. Office of Naval Research, Contract N8onr-641, T.O. 5, ONR Report No. 641-05-7, 1 July 1952.

[3] KOPONEN, A., WATERS, R.H. & ORLANSKY, J. Studies of avigational graphic aids. The relative legibility of two aeronautical charts. Contract N8onr-641-05, Memorandum No. 2, 15 March 1952.

Table III (continued)

General flight factor	Type of Projection	Information	Scale	Size	Area coverage	Cartographic detail
5. Flight speed		Varies the number of ground referents that can be utilized (inversely proportional).	Varies the size of scale that is desirable (inversely proportional).		Varies the total area coverage which is desirable (directly proportional).	
6. Flight altitude		Varies the number and size of ground referents that can be utilized (inversely proportional).	Varies the size of scale that is desirable (inversely proportional).			
7. Combat radius					Varies the total area coverage which is desirable (directly proportional).	
8. Electronic gear		Varies the type and amount of electronic information which might appear.				

Table III

Relationships between chart characteristics and various flight factors

General flight factor	Type of projection	Information	Scale	Size	Area coverage	Cartographic detail
1. Navigation procedure	Varies the suitability and convenience introduced by different projections.	Varies the type and amount of information needed on a chart and the relative importance of data included.				
2. Region flown over	Varies the accuracy and the resulting suitability of different projections.	Varies the availability of landmarks, radio facilities, etc.				
3. Accuracy required	Will vary suitability of the projection.	Varies the amount of information (directly proportional).	Varies the size of the scale (directly proportional).			
4. Navigation facilities				Space varies the allowable size of the sheet (directly proportional).		Lighting varies the suitability of color combinations used.

A demand for greater total area coverage with a fixed size of chart may force the adoption of a smaller scale.

4. Size

An increase in information with a necessary increase in chart scale forces the adoption of a larger chart size if greater total area coverage is to be attained.

5. Area Coverage

If the information and scale adjustment is set or constant, a decrease in total area coverage may be necessary if the chart is to be of a reasonable size.

6. Cartographic Detail

An increase in information, with the scale constant, may force the adoption of smaller print and symbols to avoid clutter on the chart.

The inherent difficulty of writing the requirements for a series of ideal charts should be pointed out. Cartographers are confronted with the problem of evaluating diverse factors and manipulating variables which are so interrelated that they cannot be varied independently or combined ideally. For example, a map whose scale and information are such that both area coverage and readability are quite satisfactory may be too large for convenient use in the cramped quarters of a high-speed single-cockpit plane. Ideally one would like to cut the size down to that of a book page. A photographic reduction could quickly accomplish this, but it would automatically reduce the scale. The resulting effect on the chart's readability would be highly undesirable unless perhaps a microscopic gadget were available. Simply cutting out a page-size section of the map would not have these same adverse effects. It would, however, reduce the area of the earth's surface displayed, and a high-speed plane would rapidly fly out of the area portrayed on the chart.

The alternate solutions to an actual problem, much like the one assumed, are compromises which attempt to reconcile these conflicting requirements.

1. Fold and fumble with the large sized chart.

2. Use a knee-pad gadget or a book which presents a series of cuts of the large map, with the resulting inconvenience of shifting from one map to another.[1]

3. Accept the idea of a smaller scale map with less information available for en route flying.[1] (The objection here is a lack of detail for emergencies or a shift in destination.)

Logical relationships have been shown to exist between various flight factors and chart variables. What is now required is a detailed experimental program to assign precise values of relative importance to each variable so that necessary compromises can be made on an objective basis of fact. For example, it is not known exactly which scale is best for a speed of 183 knots nor has anyone yet demonstrated that cumbersome large-area coverage charts are more desirable than small-sized charts which may entail more changes en route. However, the trends evident in present charts indicate certain preferences, and general knowledge of both air navigation and chart construction allows estimates of the situation which will approximate final answers.

[1] Undergoing evaluation by the Navy.

III. OUTLINE FOR A FAMILY OF CHARTS

The preceding section enumerated how the general characteristics of aeronautical charts logically relate to various factors of flight. It indicated that the primary function of a chart is to impart information. It also showed that the "amount and type of information presented" is the chart characteristic most closely related to variations in flight conditions.

This suggests that the development of a functional schematic for a family of charts should center upon the purpose of charts and the principal types of information they must present.

A. Major Phases of Flight

The purpose served by an aeronautical chart depends primarily upon the phase of flight in which it is used by the navigator. The navigation of any flight tends to have three separate, identifiable phases: planning, en route, and destination. These three phases contain factors which radically alter the navigator's requirements for a chart.

1. Planning Phase

The first phase takes place on the ground where the navigator can be provided with maximum facilities. Cartographers may exercise considerable freedom with the dimensions of the charts to be used during pre-flight planning. In an operations office or a ready room, an airman may well utilize large maps which yield maximum accuracy and provide enough total area coverage for planning flights between distant points. Precise measures and information obtained from a planning chart can be transferred to the charts which will be used in actual flight.

2. En Route Phase

The en route phase of navigation introduces special working conditions for the airman and places certain restrictions on the charts which he can utilise. The essential task which he must perform is to maintain a course which will bring him to the vicinity of his destination. The error which may accumulate en route (due to the effect of wind, inaccurate flight instruments, and faulty plane control) needs to be checked periodically by "fixing the plane's position" to see if the course is being maintained. If it is not, a revised course must be determined. Considerable area coverage or complete coverage between take-off and destination points is desirable. In order to fulfill reasonably well the accuracy generally required in navigating the en route phase, a chart need not provide, however, as large a scale or as much detail as required in the destination phase.

3. Destination Phase

As the destination is approached, off-course errors are magnified in relation to the time and distance left to travel, and greater alterations in course must be made to correct for such errors. The precision and accuracy necessary at the final stages of a flight, of reaching and locating a given point on the earth, require that the chart have a relatively large scale and/or convey detailed information of the immediate vicinity of the destination.

An analogy which illustrates the changes between the en route and destination phases is the motorist who ventures only with road maps to guide him from Chicago to a home in New York City. A map showing the principal roads and towns is entirely adequate and convenient to use en route. However, to locate the precise address, a detailed map of the New York streets would be necessary.

B. Basic Functional Groupings

Further consideration of chart variation will show that the en route and destination phases may involve the use of distinct charts for three major types of activity--pilotage, plotting and electronic navigation.

1. Pilotage

The predominance of land in the area being flown over and charted allows the conveying of visual fix information to supplement rather sketchy dead-reckoning procedures. Charts which concentrate primarily on conveying recognizable landmarks are basic since for some aspects of flight there is simply no substitute for visual location. (Electronic facilities are not available in all regions, devices which the planes carry are subject to breakdown, and it may not be advisable or possible to use such gear in combat territory.) Charts used for pilotage may differ among themselves primarily in their scale, which is related to the speed at which the plane may fly.

2. Plotting

The fact that most of the earth's surface consists of vast expanses of ocean water forces the design of plotting charts to handle the precise dead-reckoning necessary to navigate over such areas. Accurate plots must be maintained of the vector forces involved in order to keep track of the plane's position and to estimate the headings to be flown. If proper instruments are available, celestial or electronic fixes may be taken and plotted periodically to check position and/or correct the course to the destination. The primary concern in constructing such charts is to allow for accurate and convenient plotting. A limited amount of additional information on the chart need not interfere greatly with this procedure.

3. Electronic Navigation

The inherent accuracy, simplicity, and popularity of navigating in many areas, such as the United States, almost entirely by the use of electronic devices, and the special nature of the requisite information, make it evident that the conveying of electronic information should receive special consideration and should be unhampered by the data and design features necessary for other charts. (Cartographers and airmen are forced to accept the fact that no one chart can be made to handle efficiently all the navigational procedures which an airman might utilize.) At the present, the outstanding electronic modes of navigation are radio compass, radio range, VOR-DME, radar and loran.

The fact that several navigation procedures may be effectively combined in flights indicates that charts, while designed to fulfill the primary functions of pilotage, plotting, or electronic navigation procedures, may reasonably include information from another category which will add to their usefulness. For example, providing some electronic information on what is predominantly a pilotage chart can frequently increase its general utility without disturbing its primary function. (Other examples: A general plotting chart may include loran lines of position over water areas while prominent landmarks may be displayed when the plotting chart covers land-mass areas. Electronic facility charts may also include background data on terrain and cultural features.)

Thus, a consideration of the navigator's requirements for charts during the major phases of flight permits us to derive the following outline for a family of charts.

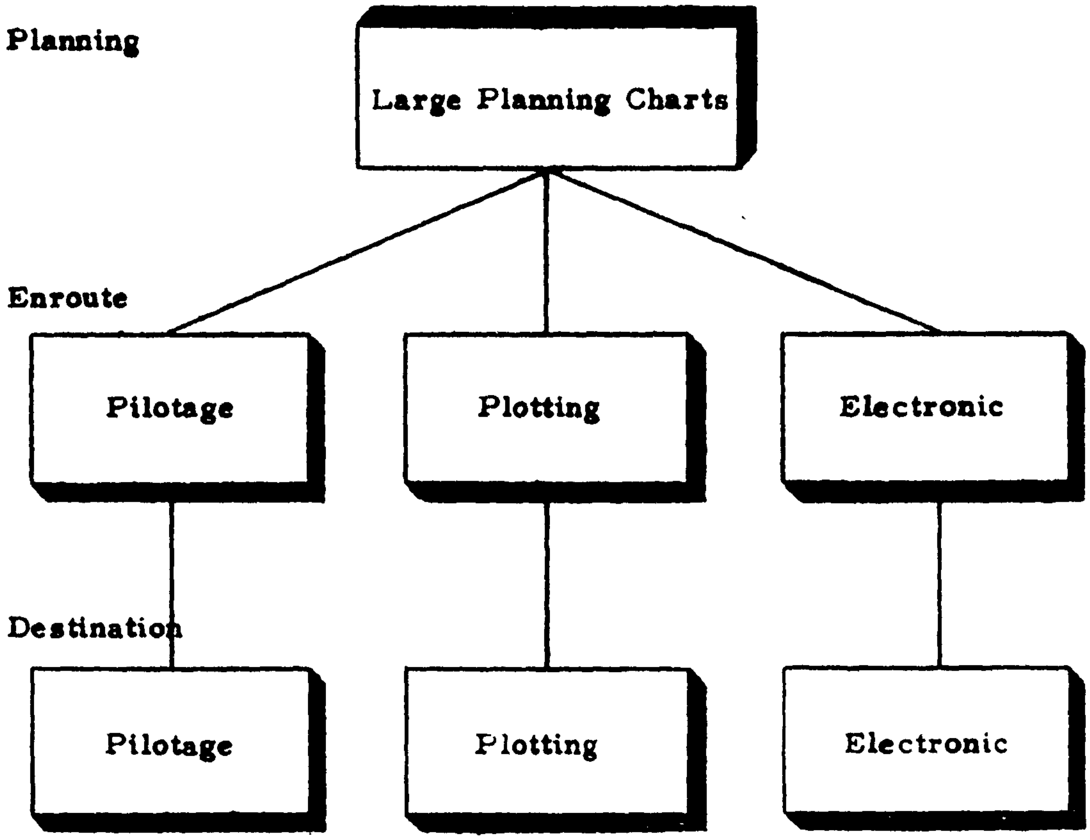


Figure 1. Outline for family of navigation charts.

Given the schematic shown in Figure 1, the next step is to review systematically the flight factors that are representative of Navy squadron missions. It is these factors that will determine the sub-varieties of charts that should be included as members of the chart family.

IV. SPECIFIC REQUIREMENTS FOR MEMBER CHARTS

In the preceding sections of this report, the general relationships between flight factors and chart characteristics were identified and the schematic for a functional family of charts was outlined. In this section operational data on the various squadron-missions of the Naval Aviation are analyzed to indicate the specific requirements for charts included as members of the family. The main emphasis is upon the sub-varieties of pilotage and plotting charts which need to be produced. (Planning charts and electronic charts involve a consideration of factors not encompassed in this investigation. Their place in the family of charts is recognized and outlined, however.) In the next and final section of this report, all of the data, including operational data, will be synthesized in a set of recommendations.

A. Planning Charts

Charts which are to be used on the ground do not present many pressing problems in functional design since there are few limits on the size, scale, and cartographic detail which might be incorporated. The principal concern is with the projection selected; unless the area coverage is very extensive the Lambert Conformal seems most satisfactory. Planning charts utilizing other projections like the Gnomonic and the Azimuthal Equidistant may also be useful since they have certain advantages, such as the location of a minimum line between take-off and destination points.

Examples of useful planning charts are the huge wall charts found in many flight operations offices. Convenient measuring devices, frequently attached to these charts, greatly facilitate the task of planning a flight. With additional study the specifications for a series of planning charts could be determined.

B. En Route Charts

The basic organizational unit in Naval aviation is the squadron. An operational squadron is composed of a varying number and type of aircraft organized as a unit to carry out prescribed flight missions. Naval Aviation Activities[1] distinguishes 14 different combinations of operating

[1] Naval aviation activities. Navy Department, Office of the Chief of Naval Operations, OPNAV Notice 05400, 1 January 1952.(CONFIDENTIAL)

squadrons and primary missions. These squadron-mission combinations may be described in terms of the flight factors influencing chart design, i.e., navigational gear, facilities and combat radius of available aircraft, and the speed and altitude at which the missions are typically flown. Table IV summarizes this information. (A 15th squadron, VR transport, has been added to the list in order to give a complete coverage of Naval air operations.) The flight factors shown in Table IV are defined below. These definitions also lead to recommendations covering chart production

1. Navigation Facilities

   a. Restricted: planes with a single or dual cockpit which have limited space and personnel for handling a chart and navigating the flight.

   b. Special: planes which have a special space and table for a full-time navigator to operate

This breakdown is made with the recognition that co-pilot navigators in dual cockpit planes operate with essentially the same restrictions for handling a chart that confront the navigator in a single-operator aircraft. Unless a special table and space is provided, "knee-pad procedures" must be used. This simple two-way breakdown is supported by the opinions of experienced pilots attending a conference with representatives of the Maps Project. The breakdown suggests that from the airman's viewpoint essentially two sizes of charts are necessary: a small one which can be handled in the cockpit and a larger one which approximates the dimensions of a navigation table

2. Flight Speed

   a. Slow - below 100 knots.

   b. Medium - 100 to 200 knots.

   c. Fast - above 200 knots.

The breakdown in speed is arbitrary, but it was made in consultation with experienced pilots. "Anything under 100 knots is slow--anything over 200 knots is considered fast." Until

Table IV

Characteristics of en route Naval flight

Squadron designation	Mission	Navigation facilities	Flight speed	Flight altitude	Combat radius	Electronic gear
1. VA	(a) Intercept	Restricted	Fast	High	Medium	Basic
	(b) Surface Attacks					
2. VA	(a) Mine Laying	Restricted	Medium	Low	Medium	Special
	(b) Surface Attacks	Restricted	Medium	High	Medium	Special
3. VC_1	(a) Surface Attacks	Special	Fast	High	Long	Special
	(b) Mine Laying	Special	Fast	Low	Long	Special
4. VC_2	All Weather ASW Patrol and Mine Laying	NO CHARTS				
5. VC_3	Airborne Early Warning (AEW)	Restricted	Medium	Low	Medium	Special
6. VC_4	All Weather Intercept	Restricted	Fast	High	Medium	Basic
7. VC_5	PhotoReconnaissance	Restricted	Fast	High	Medium	Basic

Table IV (continued)

Squadron designation	Mission	Navigation facilities	Flight speed	Flight altitude	Combat radius	Electronic gear
8. VS	ASW Patrol and Attack	NO CHARTS				
9. HU	Observation and Rescue	Restricted	Slow	Low	Long	Special
10. VP_1	ASW Patrol and Attack	Special	Medium	Low	Long	Special
11. VP_2	AEW and ASW Patrol	Special	Medium	Low	Long	Special
12. VP_3	Photo Reconnaissance	Special	Medium	High	Long	Special
13. VU	Utility Operations	NO STANDARDS				
14. HS	Anti-Submarine Attack	Restricted	Slow	Low	Short	Basic
15. VR	Transport	Special	Medium	Low	Long	Special

experimental evidence as to the precise relationship of speed to chart scale is available, this three-way breakdown, based on the opinions of the pilots consulted, seems justified. This suggests that three different chart scales will be necessary to satisfy the variation in flight speeds. The scales selected appear in a following section.

3. Flight Altitude

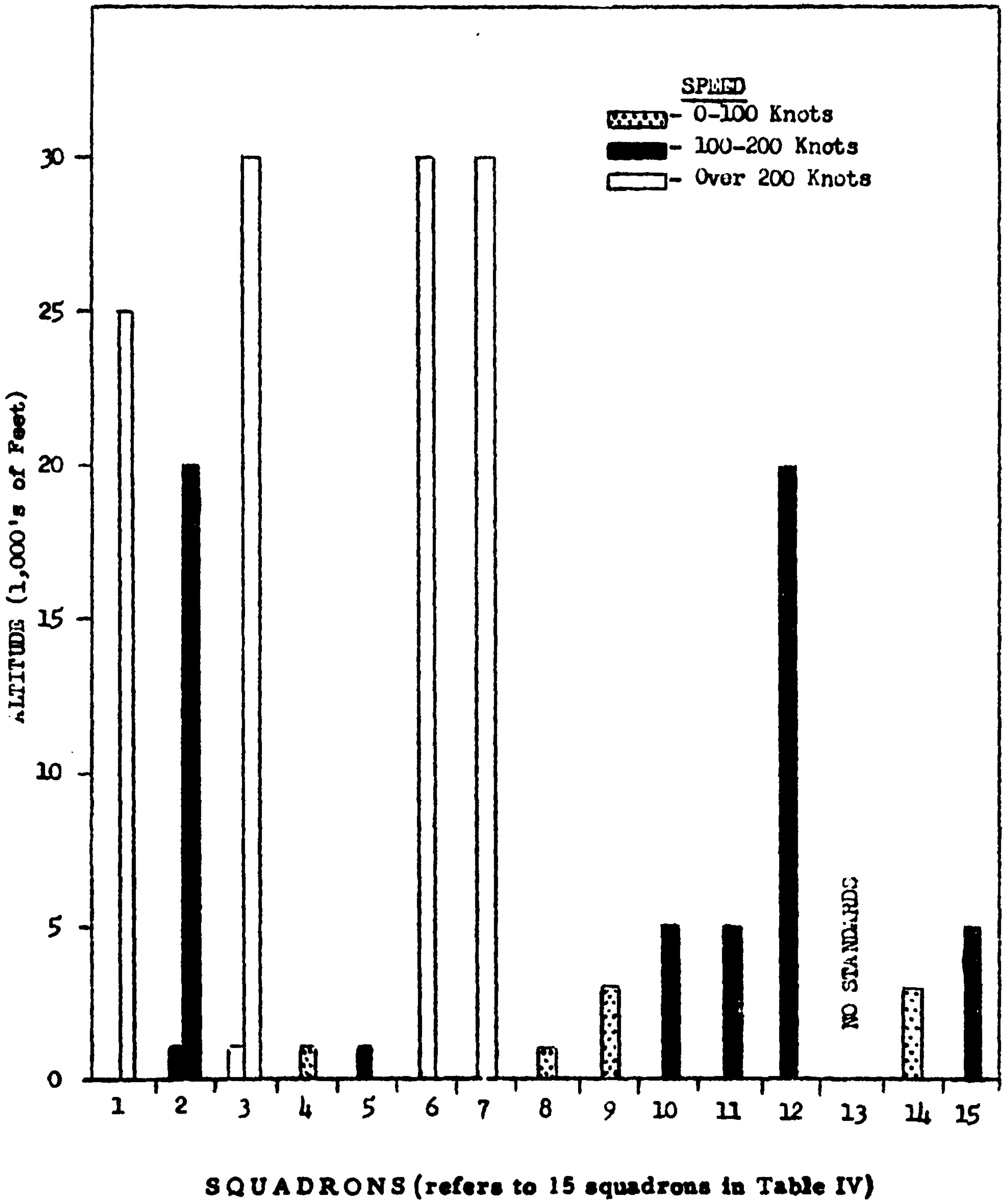
a. Low - 5,000 feet and below.

b. High - 20,000 feet and above.

Only two categories are indicated by an analysis of typical en route operating altitudes by the Office of Naval Operations. The breakdown is made apparent in Figure 2, which shows that the en route altitudes of Navy squadrons are either high or low. Medium altitudes, from 5,000 to 20,000 feet are not typical. Figure 2 also demonstrates the fact that high altitude is generally associated with high-speed and low altitude with low speed. The outstanding exception is Squadron 3 (VC-Mine Laying in Table IV) which flies fast and low.

The effect of flight altitude on the chart variables of scale and information can be taken care of in the main by the consideration of speed with which it is highly correlated. Smaller scale charts which convey less information correspond neatly to the general association of high speed and high altitude. Contradictions introduced by fast flight at low altitude or slow flight at high altitude must be compromised by accepting the dominance of the speed factor, unless the altitude is extremely high. A theoretical study by Waters and Orlansky[1] gives the minimum dimensions of 34.8 feet for any object to subtend one minute of arc at the eye from an altitude of 30,000 feet and an angle of sight from the horizontal of 30 degrees. At 30,000 feet directly above the object (line of sight 90 degrees) the minimum dimensions are

[1] WATERS, R.H. & ORLANSKY, J. The use of mathematical and meteorological data in aeronautical chart construction. Office of Naval Research, Contract N8onr-641, T.O. 5, ONR Report No. 641-05-4, 29 May 1951.



NOTE:

1. Data obtained from Office of the Chief of Naval Operations.
2. Correlation of Speed and Altitude = .91 (r_{tri}).

Figure 2. En route altitudes and speeds of Navy squadrons.

8.7 feet. These minimum dimensions approximate the size of objects which can be seen by a person with normal vision under standard meteorological conditions at the stated altitudes and lines of sight. Land masses contain an overabundance of features which exceed these dimensions. Until the flight altitudes exceed those which are under consideration in this report, these approximations do not furnish a basis for selecting the landmarks which should be included on an aeronautical chart. Until practical flight studies are completed on the relative ease of recognition of different landmarks at given altitudes, the information which is to be included on a chart must be largely a result of the consideration of speed and the allowable clutter for the scale which has been selected.

4. Combat Radius

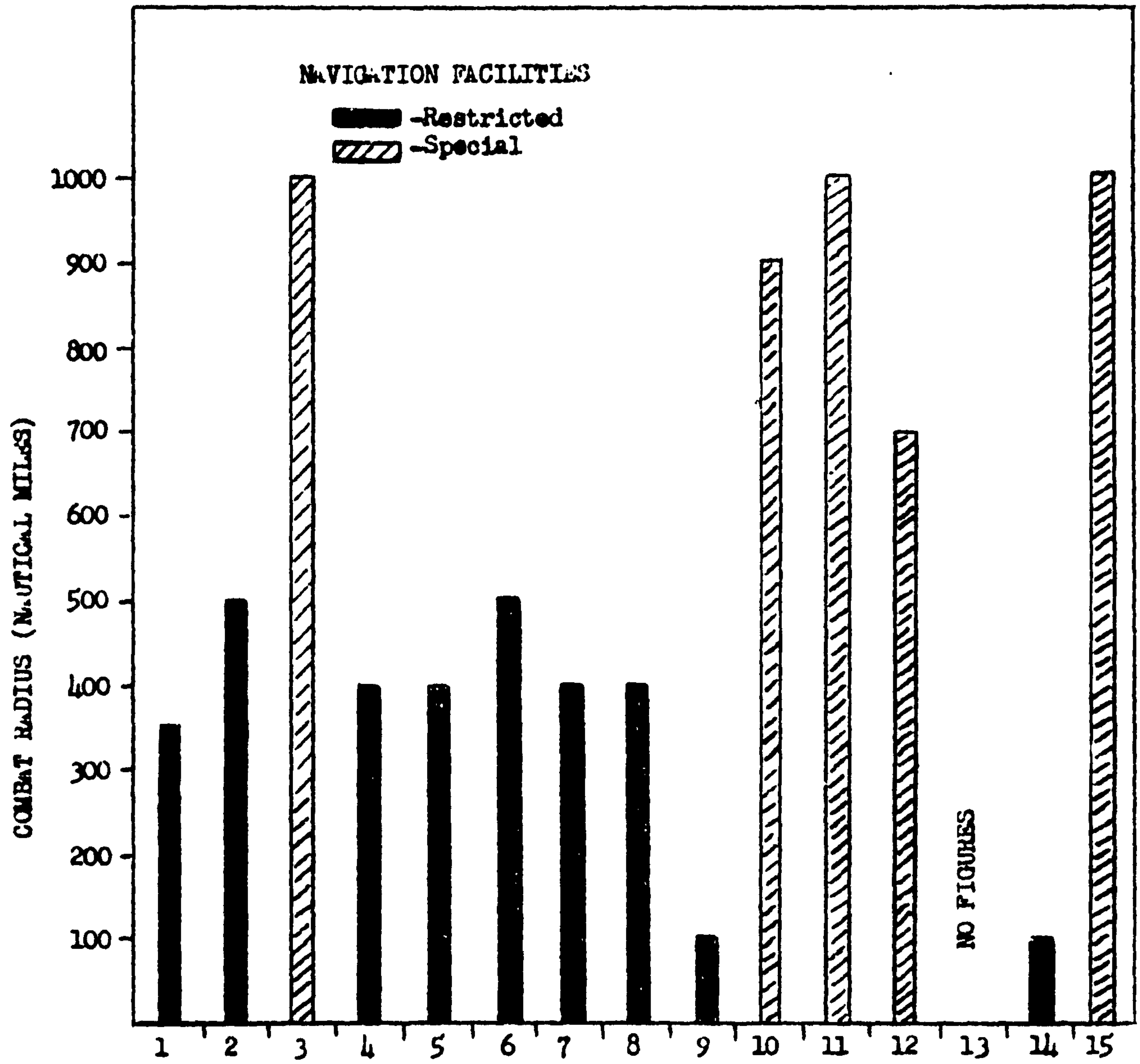
a. Short - 100 nautical miles and below.

b. Medium - 100 to 500 nautical miles.

c. Long - over 500 nautical miles.

Combat radius categories result from the analysis of data collected on various planes associated with the squadron-mission combinations. Figure 3 displays typical values for the 15 squadrons of Table IV. The figure shows values which cluster at three levels: short, medium and long distances. All of the planes capable of flying greater ranges have space for and carry a special navigator. The correlation of navigation facilities with combat radius insures that, for a given scale, differences in allowable sheet size will yield area coverages which will vary with the combat radius of the aircraft.

It is not yet possible to build charts of a convenient size, employing scales which convey frequent visual fix information and at the same time give an area coverage equal to the maximum range of many of the aircraft now employed. However, even when the area coverage of member charts in a



SQUADRONS (refers to 15 squadrons in Table IV)

NOTE:

1. Data obtained from Office of the Chief of Naval Operations.
2. Correlation of Navigation Facilities and Combat Radius = .65 (r_{bis}).

Figure 3. Combat radius and navigation facilities of Navy squadrons.

series is great, flights may take off near the edge of a map, fly in the direction of that edge and thus, necessitate an immediate change in charts en route. Unless the producing agency builds charts for flights between stated points, it must accept such possibilities with the series of charts they cut.

5. Electronic Gear

a. Basic - VHF, YG, radio compass.

b. Special - basic gear plus radar, loran and racon.

The electronic gear which Navy planes carry results in the two categories stated above. These data may be utilized to indicate the extent of electronic information which recommended pilotage or plotting charts should contain. For example, a plotting chart designed for VP_1 - ASW Patrol and Attack planes might well include information applicable to racon if racon is available in that region, but a chart designed for planes in HU - Observation and Rescue would not need to contain such data

It is assumed that the data on the 15 different squadron-missions (Table IV) supply representative coverage for the great mass of flights which the Navy conducts. The associated flight factors may be viewed as "estimated means"[1] which are typical of the related squadron-missions. When charts provide for representative combinations of flight factors, the optimum family will be approached.

The data in Table IV indicate the need for, and lead to, variations in all types of en route charts. While the Naval aircraft operate primarily over water areas, it is conceivable that land might be flown

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[1] These estimates were furnished largely by CDR Russell of the Office of Naval Operations. Additional data were supplied by CDR Stewart of the Hydrographic Office and CDR Beveridge of the Office of Naval Research.

over on any of the missions that are listed. (In Korea the Navy operates close to the enemy shore and carrier planes strike inland to enemy territory and shore installations. Furthermore, the en route characteristics listed are generally representative of flights in the United States. Thus, a VF fighter aircraft will typically fly fast and high, whether on the way to intercept an enemy or on a cross-country flight to San Diego.)

Since essentially the same characteristics apply to more than one squadron-mission, the data in Table IV reduce to eight basic combinations of flight characteristics as shown in Table V. The second column shows the squadron-missions that are associated with each combination. If the precise relationships between the various flight characteristics and chart variables were known, the next step would be to design various en route charts for each of the eight representative combinations. At the present time factual data and knowledge of our sample are insufficient to warrant such a step. An intensive job analysis and testing program would be necessary to carry out such an approach. Short of this, however, the analysis of the various squadron-missions suggests an alternate plan which does seem feasible for making tentative recommendations.

The high correlations between navigation facilities and combat radius and between speed and altitude insure that any scheme which considers only one of each pair will, in general, satisfy the remaining characteristics as they occur in Naval aviation. Thus, varying the sheet size of charts with the restricted and special navigation facilities will handle combat radius considerations - i.e., will yield charts with less and greater area coverage (scale constant). Varying the scale and information with speed will generally take care of variations in these required by altitude. In addition, the decrease in scale which accompanies higher speeds will yield greater area coverage (sheet size constant) for the higher speed planes. The latter is important since it will serve to reduce the number of changes in charts en route per unit time.

The electronic gear determines, to some extent, the additional information to be included. It may receive concern after the general dimensions of en route pilotage and plotting charts are set. The variation in these en route charts which seems justified at the present time is one in which navigational facilities and speed are dominant, resulting

Table V

Eight distinct combinations of flight characteristics

Combination	Navigation facilities	Flight speed	Flight altitude	Combat radius	Electronic gear	Squadron-Mission
1.	Restricted	Slow	Low	Short	Basic	HU Observation and Rescue HS ASW Attack
2.	Restricted	Medium	Low	Medium	Special	VA Mine Laying VC_3 AEW
3.	Restricted	Medium	High	Medium	Special	VA Surface Attack
4.	Restricted	Fast	High	Medium	Basic	VF Intercept and Surface Attack VC_4 All Weather Intercept VC_5 Photo Reconnaissance
5.	Special	Medium	Low	Long	Special	VP_1 ASW Patrol and Attack VP_2 AEW and ASW Patrol VR Transport
6.	Special	Medium	High	Long	Special	VP_3 Photo Reconnaissance
7.	Special	Fast	High	Long	Special	VC_1 Surface Attack
8.	Special	Fast	Low	Long	Special	VC_1 Mine Laying

in charts of three scales, cut in two sheet sizes, with the total area coverage incidentally varying in the right direction. (Area coverage which approaches the maximum range of flight of some planes will require the use of more than one chart in a series.)

C. Destination Charts

Accuracy and altitude figures from the Office of Naval Operations on the various squadron-missions support the general need for accurate, large scale charts to fulfill the destination or target phase of many Naval flights. The requirements for detailed information and/or a large scale is paramount; other considerations are insignificant. The figures which were obtained are presented in Table VI.

Table VI

Accuracy and altitude figures for squadron-missions during destimation phase of flights

Squadron-Missions	Final accuracy required	Final altitude (in feet)
1. VF - Intercept	Limits of visibility	Varies
2. VA - Mine Laying	200 yards	1,000
Surface Attacks	5 miles	1,000
3. VC_1 - Surface Attacks	1 mile	30,000
Mine Laying	200 yards	1,000
4. VC_2 - All Weather ASW	1 mile	1,000
Mine Laying	200 yards	1,000
5. VC_3 - AEW	1 mile	Varies
6. VC_4 - All Weather Intercept	1 mile	Varies
7. VC_5 - Photo Reconnaissance	1 mile	Varies
8. VS - ASW	1 mile	1,000
9. HU - Observation and Rescue	100 yards	Varies
10. VP_1 - ASW	1 mile	5,000
11. VP_2 - AEW and ASW	1 mile	5,000
12. VP_3 - Photo Reconnaissance	1 mile	Varies
13. VU - Utility		
14. HS - ASW	100 yards	3,000
15. VR - Transport	5 miles	1,000

The final accuracy of many missions (such as mine laying), may demand chart scales as large as 1:6,000[1]. When great accuracy is needed, special charts can be produced for the area of such operations. For a universal aeronautical series, however, a 1:250,000 scale is the largest which can be recommended. An accuracy of one mile can be plotted with this scale (1 inch = 3.4 nautical miles). In addition, sufficient basic terrain detail can be shown to indicate the visual location of normal-sized targets which might be entered on the chart (factories, dams, etc.). The scale is certainly adequate for showing the relative position of airports, small towns, etc.

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[1] MANGELSDORF, J. E., SCHREIBER, R. J., TOLCOTT, M. A. and CHANNELL, R. C. A study of the plotting and communication facilities in the chart room of UOL- equipped minesweepers. SDC Report No. 641-3-9, Contract N8onr-641, T.O. 3, 1 October 1951. (CONFIDENTIAL)

V. RECOMMENDATIONS

The operational data has been reviewed in Chapter IV in an attempt to determine the implications of the data with regard to aeronautical charts. These implications, together with other data presented in this report, have been incorporated into a set of recommendations, organized in terms of the three phases of flight activity: planning, en route and destination.

A. Planning Charts

Planning charts have received only summary concern in this report. The previous section contained a general recognition of the problem of possible projections to be used on planning charts. Specific recommendations as to size, scale, etc., are contingent on a study of factors other than those of flight which have been taken up in this report.

B. En Route Charts

1. Pilotage Charts

The general features and dimensions for a group of pilotage charts which will cover Naval flight may be inspected in Table VII. The figures on scale, size, and area coverage are first approximations which are being recommended tentatively. (A research program which will be outlined refining our knowledge of the relation of speed to scale and information will perhaps indicate that more scales are necessary or may alter the particular ratios which have been selected.)

The projections for the various series of pilotage charts are identitical. The general superiority of the Lambert Conformal Projection is readily apparent on inspection of those presently available. The following advantages have been listed:

"1. For practical purposes only one scale for the entire map.

2. All directions within standard parallels are approximately true.

Table VII.

Recommended features and dimensions for en route pilotage charts

Chart series	Projection	Information	Scale	Size	Area coverage (approximately)	Determining Flight characteristics	Associated squadron mission
1.	Lambert Conformal (Stereographic for polar regions)	Local Aeronautical Chart (Basic electronic information)	250,000	16 x 20 inches	70 x 55 miles	Slow speed and restricted facilities	HU-Observation and Rescue HS - ASW
2.	"	Revised "WAC" chart (Basic and special electronic information)	1:1,000,000	16 x 20 inches	280 x 225 miles	Medium speed and restricted facilities	VA-Mine Laying and Surface attacks VC-3-AEW
3.	"	"		22 x 29 inches	400 x 300 miles	Medium speed and special facilities	VP_1 - ASW VP_2 - AEW and ASW VP_3 - Photo Reconnaissance VR - Transport
4.	"	XJN with increased detail (Basic electronic information)	1:2,000,000	16 x 20 inches	540 x 480 miles	Fast speed and restricted facilities	VF-Intercept VC_4-All weather intercept VC_5-Photo Reconnaissance
5.	"	XJN with increased detail (Basic and special electronic information		22 x 29 inches	785 x 600 miles	Fast speed and special facilities	VCl - Surface attacks and Mine Laying

3. Great circles are very nearly straight lines.

4. When applied to large areas of E. W. Extension or to smaller sections within it is remarkably accurate.

5. Excellent projection for aeronautical charts."[1]

For polar regions the Stereographic Projection may be acceptably incorporated in the series as it is in the present World Aeronautical Charts Series. The following advantages have been listed for this projection.

" 1. It is the only azimuthal projection which has no angular distortion and in which every circle is projected as a circle, i. e., conformal as well as azimuthal.

2. Shows true directions from point of tangency.

3. Good for mapping polar regions."[1]

The information column in Table VII refers to available charts which approximate or carry the scales recommended. This reference helps to visualize the general appearance and clutter of the proposed charts. In general, the information and readability of the present Local Aeronautical Chart is quite satisfactory. The WAC chart definitely needs a revision of the information it presents. The radio information is too prominent for a pilotage chart and some of the cultural and terrain features should be deleted, especially in the region of major cities. The information which the XJN chart presents may be increased on the 1: 2,000,000 scale which is being recommended for our high-speed aircraft category. (The XJN, scale 1: 4,377,740, is seen as a pilotage chart for the future or for the present limited number of Navy jet aircraft which normally cruise at better than 400 miles per hour. Presently it may be placed in the family as a special radio facility chart.)

The information column also indicates for each chart series the extent of the electronic information which should receive consideration when it is available for the region being charted. Some electronic

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[1] Map projections and coordinate systems. Photographic Interpretation Handbook Supplement No. 19, Photographic Intelligence, Navy Department, 1 February 1946. (RESTRICTED)

data may be printed on the face of the pilotage charts without introducing too much clutter. Additional data may be printed on the back as it is on the XJN series.

Only three scales are recommended. These cover the flight factors as obtained from Naval Operations. The 1:250,000 scale is acceptable for the low-speed, low-altitutde en route flight of helicopter squadrons. For such aircraft, traveling at a ground speed of 80 knots, the rate of movement across the chart would be approximately one inch every 2 1/2 minutes. The 1:1,000,000 scale is suitable for medium-speed aircraft. At a ground speed of 150 knots, the rate of movement across the chart would be approximately one inch every five minutes. A 1:2,000,000 scale is recommended for high-speed en route flight at altitudes above 20,000 feet. On this scale, with a ground speed of 300 knots, the rate of movement across the chart is approximately one inch every 5 1/2 minutes. (The rate of movement across these charts is fairly rapid. It would be desirable to decrease this rate by utilizing somewhat smaller scales if it could be shown that less information need be depicted. Until this has been demonstrated, it is safer to present too much rather than too little for navigating at the various flight speeds.)

The charts are cut in two sizes. These correspond to the navigation facilities of the planes associated with the charts. A sheet size of 16 x 20 is acceptable for handling in a restricted space. The 22 x 29 sheet can be spread on a navigation table. Charts which are any larger are cumbersome to handle. Frequent folds, necessary with larger charts, make it inconvenient to utilize legend data (scale measure, etc.) or reverse the chart to look at electronic information, etc., which may be printed on the reverse side.

The approximate total area coverage resulting from the scale and sizes given in Table VII tends to approach the combat radius of the associated planes. Greater area coverage would be desirable, especially for flights on which the maximum range (approximately twice the combat radius) may be flown. However, scale and size are of primary importance and the area coverages as provided insure that it will seldom be necessary to make more than two changes in charts en route. Good pre-flight planning will aid such en route transfers.

The primary flight characteristics which determined the general dimensions of the recommended charts are also shown in Table VII, together with the associated squadron-missions which served as basic representative units for the flights which the Navy conducts.

2. Plotting Charts

Charts whose dimensions essentially duplicate the pilotage group appearing in Table VII are being recommended tentatively. However, the following changes and additions apply:

a. The 1:1,000,000 and 1:2,000,000 series should be produced so that some show special electronic information (principally loran lines of position) and others do not, since planes associated with charts of these scales carry both basic and basic plus special electronic gear.

b. Special "gimmicks," such as compass roses, scales, directions, etc., which can assist plotting procedures should be added to these charts.

c. A "long range" plotting chart series should be produced, utilizing the Mercator Projection, for flights over lengthy ocean areas such as between San Francisco and Hawaii. These charts should show special electronic information, and should utilize a scale of 1:5,000,000. Special sheet sizes may be justified.

3. Electronic Charts

While some aspects of electronic navigation can be provided for on charts which are designed primarily for pilotage and plotting, additional charts will be needed to facilitate the use of electronic devices. The dimensions for such charts are contingent upon additional, specialized considerations which demand further investigation to improve the efficiency of presentation. A need for essentially two categories of electronic charts can be recongnized at this time:

a. Radio Facility Charts. Most of these are now found in convenient book form. The charts can be small in size and need only approximate true spatial relationships since: 1) exact distances between points can be stated numerically, and 2) course accuracy is inherently a function of the radio devices rather than the projection or scale utilized on the chart. (A chart like the XJN may be viewed as a special chart of this type.)

b. Radar Charts. These charts must be designed to facilitate recognition of surface features and the plane's position with an airborne radar scope. Present charts attempt to simulate the scope presentation of regions charted.

C. Destination Charts

1. The 1:250,000, 16 x 20 inch series, which has been outlined for low-speed, low-altitude en route flight in previous sections of this report, is capable of functioning as general destination charts for both:

   a. Pilotage (series one in Table VII).

   b. Plotting (same chart for ocean areas).

2. In addition, special charts will be necessary for:

   a. Servicing flights in which great accuracy may be required.

   b. Indicating specific approach and landing patterns for particular airports under instrument and contact flight conditions.

D. Family of Charts

The projected family of charts now takes the form shown in Figure 4. The diagram shows the interrelationshps among the specific varieties of charts which have been described throughout this report. The squares represent the charts whose general dimensions have been set. The circles indicate recognized types of charts whose dimensions are essentially not dependent on conditions of flight (planning charts) or which require the investigation of special problems (electronic and special target charts).

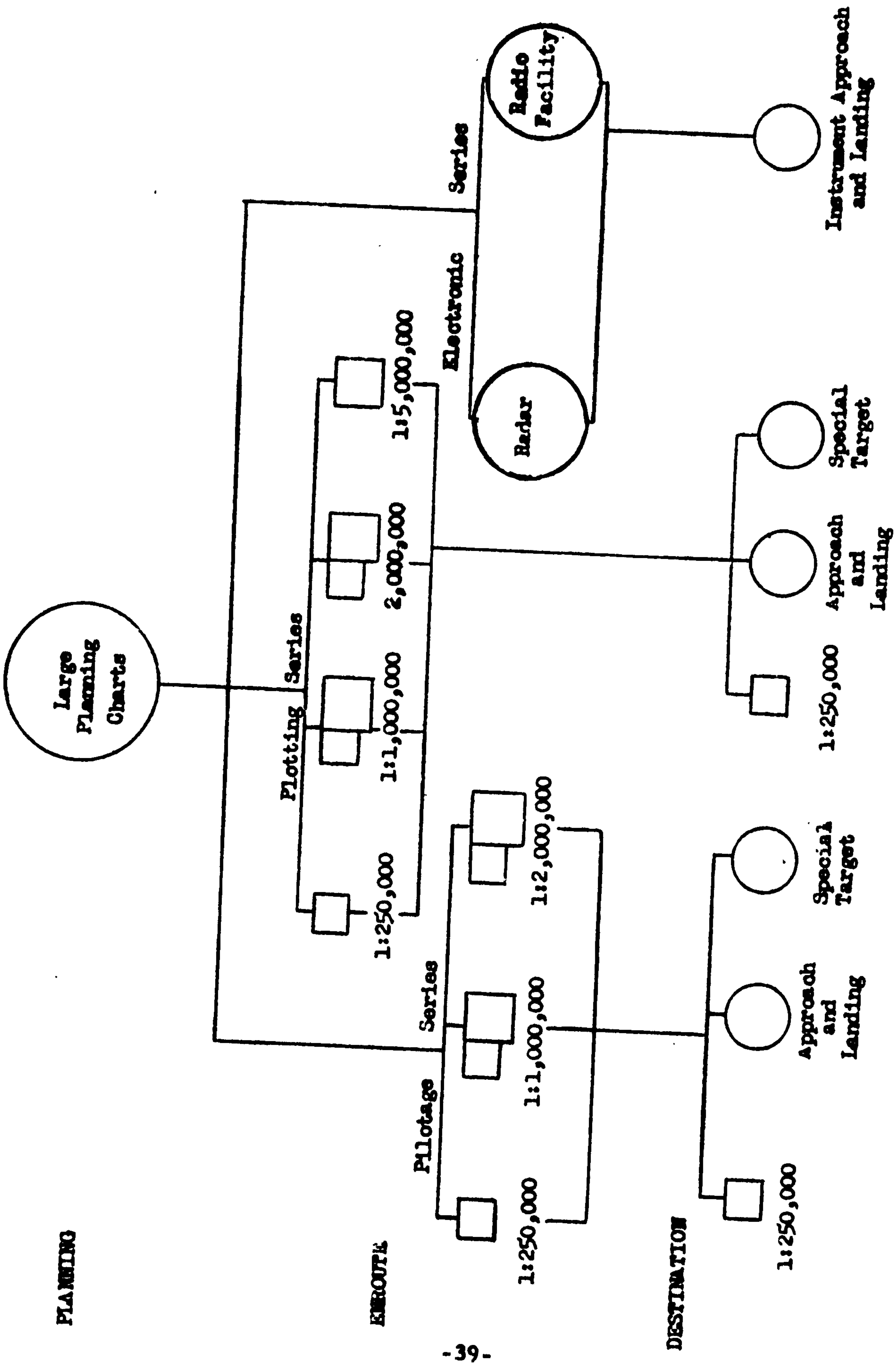

Figure 4. Diagram of projected family of charts.

Since the major differentiating characteristic of the en route charts is the scale, these values have been entered in the appropriate places. In a similar manner the different sizes recommended have been roughly indicated by squares of different size.

The squares and circles shown in the diagram total 21. This total cannot be directly compared to the total of 25 charts listed in Table I of this report, since the rules of designation are not comparable. For example: Pacific Airways Plotting Chart VR212 is produced with four different scales. This chart alone would then contribute four squares in a diagram like the one just presented. In addition, en route and destination charts of 1: 250, 000 scale in Figure 4 are the same charts. On the other hand, circled areas in this diagram may possibly involve more than one chart series. In summary, however, it may be safe to say that the proposed family indicates a reduction in the variability of chart features and a reduced number of chart series when a comparable designation plan is assumed.

Many of the present charts produced may be used provisionally to fill the roles indicated in the proposed family. Others may be excluded. For example, according to the approach adopted and the analysis made there is no apparent justification for the 1: 500, 000 scale Sectional Chart, while with the indicated revisions the WAC chart would meet the requirement for the 1: 1, 000, 000 pilotage chart in the family.

E. Future Research

The principal concern in this initial report has been to present a logical analysis of the problem of chart construction from the airmen's point of view and to indicate the general requirements for basic series of charts to meet the demands of Naval flight. The various types of charts which will be needed have been outlined to serve as a general framework for initiating detailed research programs (job analysis and testing) to refine the knowledge of chart design and indicate more specifically the features of particular types of charts. The presentation of electronic information is an area which demands special concern. Provisionally, we may accept conventional radio facility and radar charts that have been produced in recent years, but it is suggested that both deserve attention in order to improve the efficiency of presentation.

An experimental program which obtains data supporting answers to the following questions would yield important information for improving aeronautical charts.

1. How often should a fix be taken to maintain the en route accuracy which the Navy considers to be acceptable? If this were determined, exact or standard amounts of information necessary on pilotage charts could be set. With standard amounts of information available, tests could be run indicating acceptable limits "of the rate of movement" across pilotage charts of various scales.

2. What is the effect of the chart scales presently used for en route flight on the accuracy obtained with various navigation procedures?

3. What specific chart features will facilitate pilotage when a <u>fast</u> plane is required to fly at <u>low</u> altitudes which restrict the pilot's vision of the approaching horizon?

These are problems which seem immediately important, although there are many others which could be mentioned. The detailed construction of better aeronautical charts is a complex problem which requires continual research if it is to keep pace with the technical advances of aviation. The particular difficulties associated with pilotage chart design suggest that in the future some mechanical film projecting device might be utilized which could vary the chart scale, area coverage, and symbolic detail to suit the changing demands of flight and could also be equipped with gadgets to take over some dead-reckoning or plotting functions. The primary tactical objection to the development of alternate <u>electronic</u> devices which simplify navigation such as the radio compass is that they depend on units external to the plane (ground facilities) which may be utilized and/or jammed by the enemy. In any case, however, the fundamental necessity of conveying spatial relationships to human operators insures that aeronautical charts will play a continual role in air navigation.